PREDICTING HEIGHT GROWTH OF YOUNG PINUS KESIYA

FROM SOIL-PLANT NUTRIENTS AND NEEDLE TRAITS

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บทคัดย่อ

แปลงทดลองถิ่นกำเนิดของไม้สนสามใบสองแห่งซึ่งถือปฏิบัติงานภาคสนามของการศึกษาครั้งนี้ ตั้งอยู่ที่อำเภอท่าแซะ จังหวัดชุมพร และที่ห้วยบง จังหวัดเชียงใหม่ โดยที่ห้วยบงมี ๑๘ ถิ่นกำเนิดและปลูกก่อนที่ท่าแซะมี ๑๑ ถิ่นกำเนิดหนึ่งปีเต็ม การเก็บตัวอย่างดินและใบสนได้กระทำในเดือน ธันวาคม พ.ศ.๒๕๒๒ ซึ่งขณะนั้นต้นไม้ในแปลงทดลองที่ห้วยบงมีอายุ ๔ ปีครึ่ง ตัวแปรอิสระที่ใช้ในการคำนวณหาการเจริญเติบโตทางความสูงของต้นไม้โดยอาศัยสมการสหสัมพันธ์มีทั้งหมด ๒๕ ตัว อันได้แก่ เส้นผ่าศูนย์กลางเพียงอก ลักษณะของใบ ปริมาณธาตุอาหารในใบ และปริมาณธาตุอาหารในดิน ผลการศึกษาพอสรุปได้ว่าลักษณะบางอย่างของใบเช่น น้ำหนักแห้ง สี และความยาวสามารถใช้ปริมาณการเจริญเติบโตทางความ-สูงของไม้สนสามใบได้ ทว่า ถ้าจะให้ถูกต้องแม่นยำยิ่งขึ้น ก็ควรประมาณการ จากปริมาณธาตุอาหารทั้งในดินและในใบ ถ้าแบ่งตัวแปรออกเป็น ๓ กลุ่ม ก็พบว่าการวิเคราะห์ดินให้ผลน่าเชื่อถือกว่าการวิเคราะห์พืช และการวิเคราะห์พืชก็ให้ผลถูกต้องกว่าการใช้ลักษณะของใบเป็นตัวชี้ ครั้นเมื่อสร้างสมการสหสัมพันธ์โดยใช้ตัวแปรทั้ง ๒๕ ตัว พร้อมกันก็พบว่า ๘๕ เปอร์เซ็นต์ของความผันแปรทางความสูงของไม้สนที่ห้วยบงขึ้นอยู่กับเส้นผ่าศูนย์กลางเพียงอก ในขณะที่ ๗๓-เปอร์เซ็นต์ของความผันแปรดังกล่าวของไม้ในแปลงทดลองที่ท่าแซะขึ้นอยู่กับน้ำหนักแห้งของใบ ปริมาณธาตุอาหารพืชทั้งโดยการวิเคราะห์ใบวิเคราะห์ดินมีผลต่อการเจริญเติบโตทางความสูงของไม้สนที่เชียงใหม่และชุมพรน้อยมาก คือเพียง ๙ เปอร์เซ็นต์และ ๑๔เปอร์เซ็นต์ตามลำดับเท่านั้น อันสรุปได้ว่า ประเทศไทยและประเทศที่กำลังพัฒนาทั้งหลายยังไม่จำเป็นต้องใส่ปุ๋ยสวนสนสามใบในขณะที่ต้นไม้ยังมีอายุน้อย

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ABSTRACT

Field investigatior was carried out at two provenance trial plots in southern and northern Thailand where were considerably different in elevation, rainfall, and distance from the sea. Seeds from eighteen sources were planted at the dry-highland site one year prior to planting the eleven provenances at the wet-lowland planting site. Nine of them were common to both plantations. Soil and foliage samples were collected in winter 1979, while the northern-plantation trees were four and half years old. The provenance-mean values of twenty-five variables including dbh, needle traits, foliage nutrients, and nutrients in soil were used to estimate total height by stepwise multiple linear regression technique.

The results showed that such needle traits as dry weight, color, and length could be considered the useful tool in predicting tree height in the field. For more accuracy, either the levels of foliage nutrients or soil minerals were recommended. Based on the correlation coefficients obtained, the order of reliable prediction was soil analysis = foliar analysis needletraits for wet site in Peninsula and soil analysis foliar analysis needle traits for dry site in the North. A combination of all parameters revealed that dbh alone accounted for 85 percent of height variability at northern plantation while needle weight accounted for 73 percent of height variation in southern plot. Tree nutrition explained 9 percent and 14 percent of the variation in height at dry site and wet site, respectively, suggesting that fertilization was not necessary for young plantation pine, especially in such developing countries as Thailand.

Introduction

Locally known as "SON SAM BAI", Pinus Kesiya Royle ex Gordon is on of the only two Pinus species native to Thailand. Original of Khasi Hills in Assam, it extends in the most higher parts of Southeast Asia, especially in eastern Burma and northwestern Thailand. In Thailand, Khasi pine occurs mostly either in disjointed patches or as isolated occurrences associated with Pinus merkusii, oaks, and some drought-tolearant Dipterocarps.

Since the Royal Thai Government has considered Pinus kesiya as a major raw material for pulp and paper industry, an intensive program of pine plantation was started in 1963. Five years later, the Pine Improvement Center was set up aiming to promote the silvicultural and genetic research of local and introduced conifers as well as of other tree species suitable for pulp and paper industry. Recently, the Center estimated a rotation age of 18 - 20 years for pulp wood production of this species (Granhof, 1979). As research of the related fields become moreextensive, the expected rotation could be shortened leading to the successful reforestation program.

It is, therefore, an objective of this investigation to look at the nutritional aspects of Pinus kesiya in association with tree growth. The knowledges gained are expected to be helpful from a nutritional point of view.

Experimental Method

Study Area

The study area was located at two provenance trial plots, one at Hueyhong, Chiangmai province in the North and another at tha Sac, Chumporn procince in the South (Figure 1). Both are substations of Pine Improvement Center administered by the Royal Thai Forest Department Elevation, rainfall, and distance from the sea are considerably different between these two planting sites of more than 1,000 km longitudinally apart.

The northern plantation is located at 8000 m above sea level with the distance of several hundred kilometers from the Ocean. The 1,239-mm annual rainfall is unevenly distrihuted, having the dry period from early December to mid-April (Thaiutsa, 1981). Location of southern plantation considered outside the natural range of Pinus kesiya is in Malayan Peninsula, about 15 km from Gulf of Thailand, and at elevation of 100 m. The amount of rainfall is of 2,033 mm annually with only five weeks of dry period in March and early April. The Chumporn plantation is surrounded by rubber plantation (Hevea brasiliensis) with a small village nearby, while the Chiangmai plantation is in the natural stand of Dry Dipterocarps.

Experimental Design

The randomized complete hlocks with four replications were located at both sites. Flocks were treated as replications were provenances as treatments. Five-month-old seedlings of eithteen provenances were planted

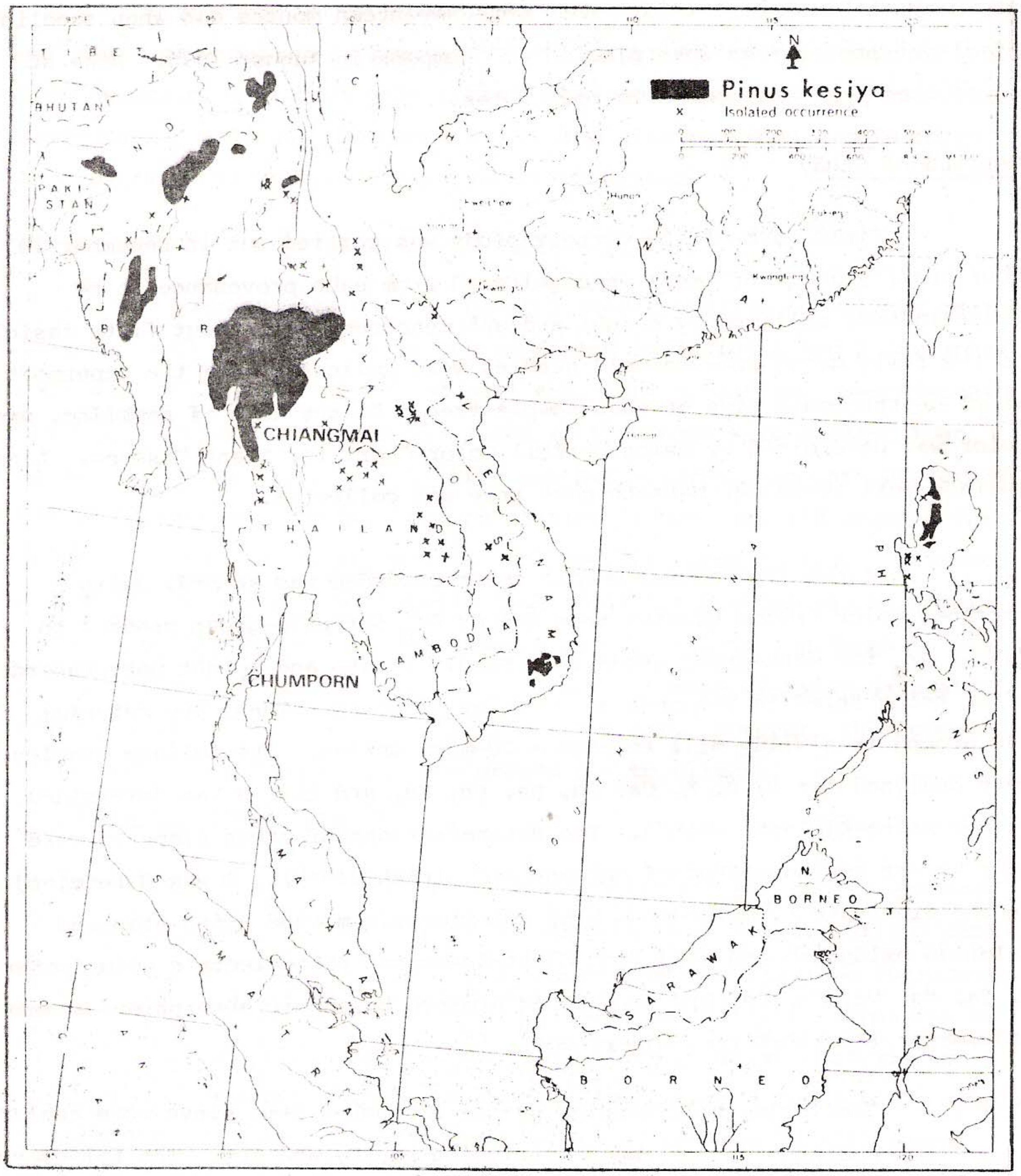

Fig. 1. Natural distribution of *Pinus kesiya* and its study sites at Chiangmai and Chumporn.

at Chiangmai in August 1975. They were seventeen months old when seedlings of eleven provenances were planted at Chumporn in August 1976. Nine of those seedlots were common to both sites.

Menthod of Study

Field work of the current study was carried out in December 1979. Four healthy dominant trees were selected from each provenance to be investigated, followed by height and abh measurements. About fifty fasicles of the fully grown one-year-old needles were collected from the uppermost whorl on the south side of each sample tree. At the time of sampling, needle color was determined by using Munsell Color Chart for Plant Tissues. Also, surface soil (0-15 cm) beneath each tree was collected.

In the laboratory, needle color recorded was scored, using thirteen color grades ranging from 2.5 GY $6/_8$ for pale-green grade 1 to 7.5 GY $4/_4$ for dark-green grade 13. Needle length and weight were recorded after being fried in the oven at 70 C for 24 hours. Then, the material was ground in a Wildy mill to pass a 20-mesh screen. The foliage samples were analyzed for n, P, K, Ca, Mg, Na, Mn, Fe, and Zn. N was determined by the micro-Kjeldahl method. The determinations of other elements were made by wet ashing method of Johnson and Ulrich (1959). P was determined on the digestate by molybdenum blue colorimetric method using stannous chloride oxidation and read from Klett-Summerson photoelectric colorimeter. K, Ca, Mg, Na, Mn, Fe, and Zn were determined by atomic absorption spectrophotometer (Perkin-Elmer, Mòderl 303).

Similarly, soil samples passed through a 2-mm sieve were analyzed for those correspendign elements including pH, C, and CEC. The following techniques were employed in soil chemical analyses : pH by pH meter read from 1:: 1 soil : water solutions; C by dry combustion method; N by macro-Kjeldahl method; available; available ; by Erary II method; and the rests by ammonium acetate extraction techniques.

The provenance-mean values were used for stepwise multiple linear regression analysis, treating total height as the dependent variable. In this analysis, variables were arranged in equations with the order of decreasing F values. The computer program also provided simple correlation coefficients between all parameters examined.

Results and Discussion

The summary data on tree growth, needle traits, as well as on the foliage and soil nutrient levels are presented in Tables 1 and 2 in order to present a general picture of those soil and plant variables. Surprisingly, height and diameter of the planted pines in the South were greater than those in the North, expecially if tree age and natural range are concerned. As mentioned earlier, the southern plantation is one year old younger than the northern ones, and it is outside the species natural range. Without regarding to the nutritional aspect, such great differences may be simply drawn to climatic influences. The amount of rainfall in the North is 40 percent less than that in the South, and the number of rainy days at Chiangmai is of 125 while it is of 209 at Chumporn. However, this paper is not focused on variation in tree growth due to climate.

Tree Growth and Needle Traita

Although most morphological characteristics of needles are easy to be estimated, little is known on the approximation of tree growth from needle traits. The current findings revealed that some foliage characters could be considered the useful tools in predicting growth performances of Pinus kesiya, especially those in the field where chemical analysis is hardly possible. Height and diameter, for example, were found to be simply correlated with dry weight, color, and length of needles as illustrated in Figure 2. Among those, needle weight seemed to he the best predictor, since it showed highly significant with both height and dbh at Chumporn (Eguations 9 and 12) and significant at 5 percent level at Chiangmai (Eguations 3 and 6). This is due partly to the close relationships between needle weight and foliage nutrients. For young Pinus kesiya planted in southern Thailand, Thaiutsa (1981) noted that the levels of nitrogen, potassium, and iron in needles can explain 37 percent of the needle-weight variability.

Height and diameter growth equations developed from needle parameters were as follows :-

Chiangmai : $Ht = 0.222 \text{ length} - 1.289$ (1)

$R = 0.58^{*}$

$Ht = 1.283 + 0.216 \text{ Color}$ (2)

$R = 0.62^{**}$

$Ht = 1.249 + 1.991 \text{ Weight}$ (3)

$R = 0.58^{**}$

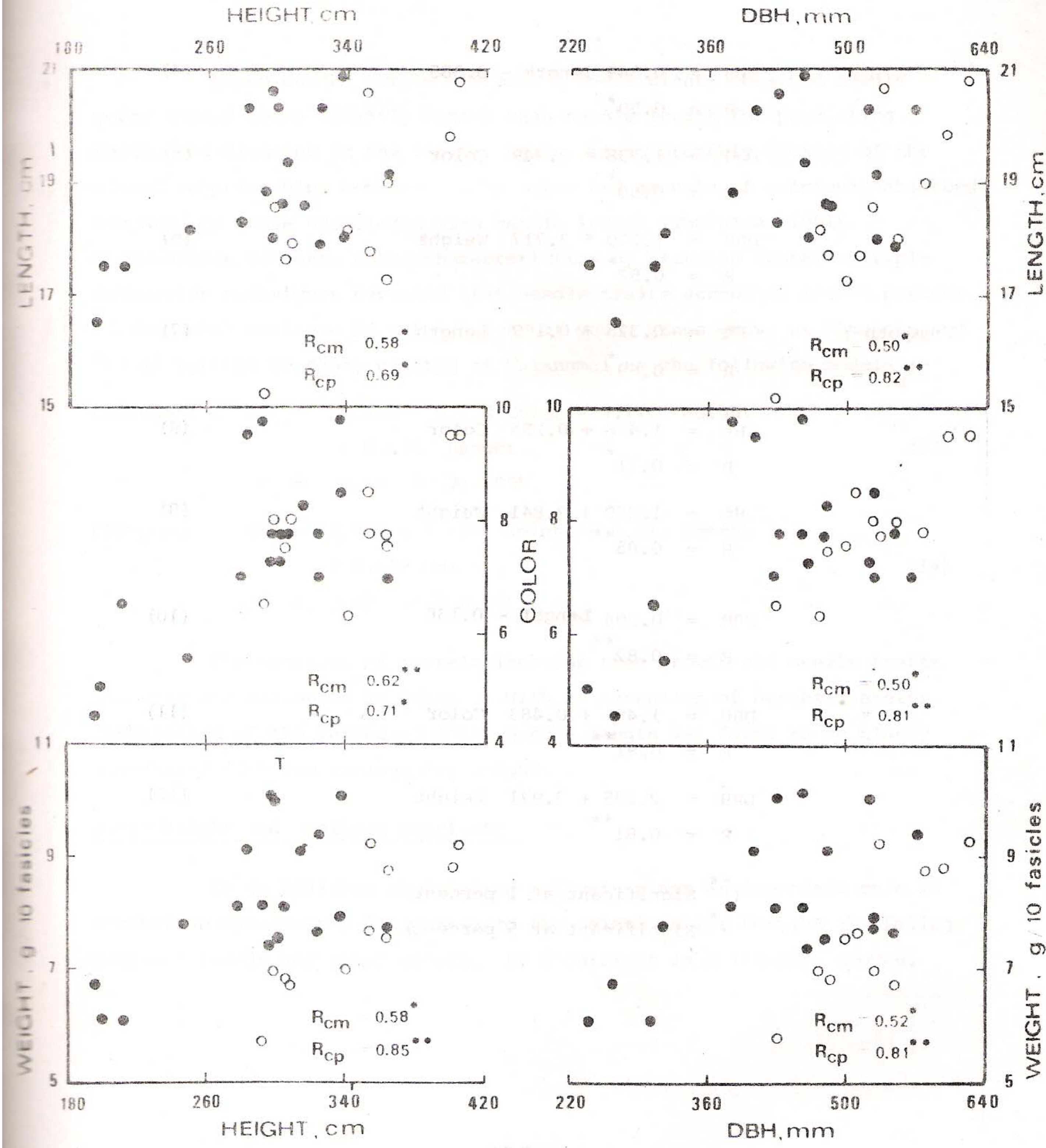

Fig. 2. Relationships between tree growth and needle traits of *Pinus kesiya* planted at Chiangmai (●, cm) and Chumporn (o, cp).

Note : ** significant at 1 percent level

* significant at 5 percent level

	DBH = 0.349 length - 3.085		(4)
	R = 0.50*		
	DBH = 1.738 + 0.349 Color		(5)
	R = 0.50*		
	DBH = 1.270 + 3.717 Weight		(6)
	R = 0.52*		
Chumporn :	Ht = 0.325 + 0.169 Length		(7)
	R = 0.69*		
	Ht = 1.426 + 0.255 Color		(8)
	R = 0.71*		
	Ht = 1.269 + 2.841 Weight		(9)
	R = 0.85**		
	DBH = 0.294 Lenght - 0.136		(10)
	R = 0.82**		
	DBH = 1.466 + 0.483 Color		(11)
	R = 0.81**		
	DBH = 2.235 + 3.971 Weight		(12)
	R = 0.81**		

(** Significant at 1 percent
* Significant at 5 percent)

Eased on the simple regression coefficients obtained needle color tended to be slightly better than needle length for predicting height and diameter in the field. Again, it is probably because of the closed relationships between needle color and amounts of nutrients absorbed compared to those associated with needle length (Thaiutsa, 1981). A comparison of these three characteristics by stepwise linear multiple regression techniques revealed that needle traits accounted for 80 percent of the total variance in total height of young pines grown at Chumporn and for 47 percent of those planted at Chiangmai as the following models :-

Chiangmai : Ht = 0.188 + 0.134 Color + 0.710 Weight + 0.058 Lenght (13)

R = 0.69 ($P > 0.05$)

Chumporn : Ht = 2.701 + 3.689 Weight - 0.111 Length + 0.073 Color (14)

R = 0.89 ($P > 0.01$)

The matrices of correlations for tree growth and needle traits examined are presented in Table 3, With an exception of height-diameter correlation of the Chiangmai data, needle length was found to be highly associated with the foliage dry weight.

Total Height and Foliage Nutrients

It is believed that foliar analysis plays an important role in vegetation management, due partly to the relationships between the foliage nutrient levels and plant growth. If a nutrient is a limiting growth,

Table 3. Correlation matrix between height and needle traits at Chiangmai and Chumporn planting sites

	Height	DBH	Color	Weight	Length
		CHIANGMAI			
Height	1.00	0.92**	0.62**	0.58**	0.58**
DBH		1.00	0.50*	0.52**	0.50*
Color			1.00	0.57*	0.60**
Weight				1.00	0.89**
Length					1.00
		CHUMPORN			
Height	1.00				
DBH	0.71*	1.00			
Color	0.71*	0.81**	1.00		
Weight	0.85**	0.81**	0.68*	1.00	
Length	0.69*	0.82**	0.58	0.91	1.00

** Significant at 1 percent level

* Significant at 5 percent level

increase in nutrient supple will result in increasing concentration in plant tissues leading to an increase in growth (Goodall and Gregory, 1947; Thomas, 1937). Ulrich (1952) nointed out that the relationship between foliar nutrient concentration and crop yield may be linear or curvilinear depending on whether the element studied is required continuously or only for specific stages in the life cycles of the plant. For such a short-term research as the current investigation, liner regression has been applied to explain such relationships.

The R values given in Tables 4 and 5 indicate that only nitrogen is correlated with total height at both sites. The relationship is negative at Chiangmai but it is positive at Chumporn. At Chumporn, the increased total height is also simply associated with low level of calcium. However, it is too early to make a valid conclusion that height growth of southern plantation pine is dependent upon nitrogen and calcium, because there are interactions among elements. Calcium, for instance, is associated with magnesium, manganese, and zinc. Therefore, the multiple regression developed suggested deficiencies of nitrogen, iron, and manganese as the foloowing equation:

$$\text{Chumporn}: \quad Ht = 5.823\ N + 0.0089\ Fe - 0.103\ Zn + 0.0069\ Mn - 4.730 \qquad (15)$$

$$R = 0.96 \quad (P < 0.01)$$

Furthermore, the equation revealed an excessive amount of zinc. On the basis of this foliar analysis, the levels of nitrogen, iron, zinc and manganese explained 92 percent of the variance in total height of Pinus kesiya planted at Chumporn with the standard error of estimate was $\pm$ 14.32 cm.

In a manner similar to the Chumporn data, multiple regression analysis between the foliage nutrients and total height at Chiangmai was expressed as follows:

$$\text{Chiangmai} : Ht = 4.907 - 2.426\ N + 6.847\ Mg - 0.00081\ P + 0.0148\ Fe \qquad (16)$$

$$R = 0.73 \quad (P > 0.05)$$

Equations 15 and 16 indicated that only nitrogen and iron were common to both sites for predicting height growth. However, variables arranged in these equations with the order of decreasing F values showed that iron deficiency at Chiangmai plantation was less severe than that at Chumporn. The current result, especially on nitrogen, accords with some previous investigators who noted the role of nitrogen on height growth of Pinus echinata, Pinus rigida, Pinus resinosa, and Pinus strobus (Hobbs, 1944); Pinus sylvestris (Leyton and Armson, 1955); and Pinus radiata (Raupach and Clarke, 1978).

The reason why foliar nutrients explained 92 percent of total height variability on wet site, but only 53 percent on dry site is a question to be answered. This is a disadvantage of foliar analysis providing only one point in the total picture of tree growth which Lavender (1970) warned that "The data obtained from properly conducted foliar analyses can indicate which element or elements are deficient, but they cannot define the reasons for the deficiencies or show how to overcome them effectively".

Total Height and Nutrients in Soils

The determination of relationships between foliage nutrients and the corresponing elements in soils show that only magnesium in needles from Chiangmai was found to be associated with the amount of soil magnesium at 5 percent level having the R value of 0.53. Poor relationships found in each pair of other elements are not surprising, since similar outcomes were reported by several investigators.

Cech et al. (1974) worked with Pinus nigra after being planted in the field for one growing season. They were unable to correlate the amounts of all fourteen elements observed in soil with those in needles. The possible reason pointed out from that study was the immature seedlings with a suggestion for further attempts after the following growing seasons. Rahman (1970) also failed to relate most soil nutrients to the nutrients in needles of mature Pinus ponderosa growin in Pacific Northwest. According to his study, only nitrogen, phosphorus, and magnesium contents in needles were positively associated with the corresponding nutrients in soil. Other minerals including potassium, calcium, sodium, manganese, iron,zinc, copper, and molybdenum did not show any relationships.

Poor correlations reported here may partly be due to method of chemical analysis. Wells (1965) sampled soils and needles of the 5-year-old Pinus taeda monthly throughout the year. Different methods of soil analysis were used to determine the levels of nitrogen, phoshorus, potassium, calcium, and magnesium. Simple correlation coefficients between the soil test values and the foliage nutrient percentage were found to be varied from technique to technique. For instance, mineralized nitrogen was more highly correlated with percent nitrogen in the needles than was the total nitrogen. Available phosphorus obtained from Truog and Bray II methods was more closely related to percent phosphorus in needles than was the total phosphours.

However, it is of interest to note that the current findings agree well with the results reported by Wells (1965). Among five pairs of soil-plant nutrients examined (i.e., N, P, K, Ca, and Mg), magnesium was noted to be the highest R value. It was pointed out earlier that magnesium was the only element which its level in soil and that in foliage were associated with each other.

Total height and dbh as related to soil chemical propertics are presented in Table 6 suggesting an excessive percentage of total carbon for tree height of Chiangmai plantation. The amounts of calcium and CEC at this planting site also tended to be slightly excessive. Althought Platteborze et al. (1971)reported a significant correlation between soil available phosphorus and total height of Pinus caribaea grown in western Malaysia where climate is similar to the Chumporn planting sits, an individual soil character cannot be correlated with height growth of Pinus kesiya planted in southern Thailand. However, the matrices of correlation expressed in Tables 7 and 8 show that some properties are associated with other, for instance, carbon with nitrogen and nitrogen

Table 6. Correlation coefficients between soil chemical properties and tree growth at two plantations

Soil properties	Chiangmai		Chumporn	
	Height, m	DBH, cm	Height, m	DBH, cm
pH	0.01	-0.07	0.12	0.11
C, %	-0.69**	-0.53*	0.17	0.45
N, %	-0.19	-0.08	-0.03	0.37
P, ppm	-0.28	-0.18	-0.08	0.19
Available K, ppm	0.24	-0.10	0.03	0.23
Exch. K, Meq/100 g	0.06	0.01	0.00	0.00
Ca, meq/100g	-0.53*	0.51*	-0.02	0.20
Mg, meq/100 g	-0.02	0.01	-0.10	0.29
Na, meq/100 g	0.30	0.29	-0.10	0.07
Fe, meq/l	0.06	-0.06	0.20	0.56
Mn, meq/l	0.21	-0.33	0.45	0.30
Zn, ppm	0.26	0.17	0.36	0.07
CEC, meq/100 g	-0.55*	-0.47*	-0.11	0.19

** Significant at 1 percent level

* Significant at 5 percent level

Table 7. Correlation matrix between height and soil nutrients at Chiangmai plantation

	Height	1	2	3	4	5	6	7	8	9	10	11	12
Height	1.00	0.01	-0.69	-0.19	-0.28	-0.24	-0.53	-0.02	0.30	0.06	-0.21	0.26	-0.55
1		1.00	0.16	-0.04	0.16	0.04	0.44	0.43	0.03	0.19	0.39	-0.30	0.14
2			1.00	0.71	0.28	0.44	0.74	0.49	-0.15	0.09	0.11	-0.44	0.77
3				1.00	0.10	0.61	0.39	0.46	0.29	-0.38	0.11	-0.52	0.61
4					1.00	0.54	0.06	0.12	0.05	-0.34	-0.15	-0.34	0.32
5						1.00	0.18	0.43	0.16	-0.54	0.07	-0.40	0.60
6							1.00	0.64	-0.02	0.08	0.15	-0.34	0.79
7								1.00	0.17	-0.02	0.24	-0.44	-0.69
8									1.00	-0.43	0.24	-0.45	0.04
9										1.00	-0.07	0.40	-0.34
10											1.00	-0.32	0.09
11												1.00	-0.47
12													1.00

$R_{0.01}$ *(16 d.f.) = 0.59

$R_{0.05}$ (16 d.f.) = 0.47

Numerical code

1 = pH
2 = C, %
3 = N, %
4 = P, ppm
5 = Available K, ppm
6. = Ca, meg/100 g
7 = Mg, meg/100 g
8 = Na, meg/100 g
9 = Fe, meg/l
10 = Mn, meg/l
11 = Zn, ppm
12 = CEC, meg/100 g

Table 8. Correlation matrix between height and soil nutrients at Chumporn plantation

	Height	1	2	3	4	5	6	7	8	9	10	11	12
Height	1.00	0.12	0.17	-0.03	-0.08	0.03	-0.02	-0.10	-0.10	0.20	0.45	0.36	-0.11
1		1.00	0.43	0.23	0.50	0.83	0.14	0.45	0.60	-0.06	-0.45	-0.47	0.19
2			1.00	0.92	0.69	0.18	0.08	0.77	0.80	0.20	-0.64	-0.55	0.67
3				1.00	0.61	-0.04	0.20	0.72	0.73	0.27	-0.60	-0.50	0.82
4					1.00	0.52	0.25	0.59	0.72	0.07	-0.38	-0.33	0.63
5						1.00	0.46	0.39	0.48	-0.05	-0.17	-0.07	0.16
6							1.00	1.36	0.31	0.36	0.15	0.34	0.57
7								1.00	0.76	0.23	-0.63	-0.46	0.59
8									1.00	-0.06	-0.70	-0.59	0.72
9										1.00	0.08	0.14	0.03
10											1.00	0.76	-0.34
11												1.00	0.19
12													1.00

$R_{0.01}$ (9 d.f.) = 0.74

$R_{0.05}$ (9 d.f.) = 0.60

<u>Numerical code</u> 1 = pH

2 = C, %

3 = N, %

4 = P, ppm

5 = Available K, ppm

6 = Ca, meg/100 g

7 = Mg, meg/100 g

8 = Na, meg/100 g

9 = Fe, meg/l

10 = Mn, meg/l

11 = Zn, ppm

12 = CEC, meg/100 g

with CEC. The interactions between nutrients may play greater role on tree growth rather than a single element does.

If all twelve soil parameters are combined together by multiple regression technique, the result revealed that 90 percent of total height variability of the North was controlled by soil carbon, nitrogen, magnesium, CEC, and manganese as the following model :

$$\text{Chiangmai}: \quad Ht = 4.586 - 2.438\,C + 38.054\,N + 2.505\,Mg - 0.496\,CEC - 1.214\,Mn \qquad (17)$$

$$R = 0.95 \quad (P > 0.01)$$

Similarly, manganese, carbon, nitrogen, and phosphorus were the major soil minerals affecting height growth of Pinus kesiya grown in the South. They accounted for 92 percent of total height described by Equation 18 as follows :

$$\text{Chumporn}: \quad Ht = 1.757 + 5.663\,Mn + 5.434\,C - 53.738\,N - 0.840\,P \qquad (18)$$

$$R = 0.96 \quad (P > 0.01)$$

The standard error of estimate was of ± 14.70 cm. It is of interest to note for Chumporn plantation that the multiple R value and the value of stand error obtained from soil analysis (Equation 18) are definitely equal to those obtained from plant analysis (Equation 15). It suggests that either needle parameters (Equation 14), foliage nutrients (Equation 15), or nutrients in soil (Equation 18) can be considered a useful predictor of total height of this young pine grown in southern Thailand. Unlikely, soil analysis provides the highest correlation of determination (Equation 17) followed by foliar analysis (Equation 16) and needle traits (Equation 13) for northern planting site.

Total Height and All Soil-Plant Variables

Finally, the predictive models were developed from all variables recorded by modifying stepwise multiple regression technique as the following results :

Chiangmai : $Ht = 1.171 + 0.382\ Dbh - 0.715\ soil\ C + 0.00046\ foliar\ P + 0.486\ needle\ weight$ (19)

$R = 0.97 \quad (P > 0.01)$

Standard deviation $= \pm\ 11.92$ cm

Chumporn : $Ht = 2.038 + 1.037\ needle\ weight - 10.721\ foliar\ Mg + 0.413\ Dbh$ (20)

$R = 0.97 \quad (P > 0.01)$

Standard deviation $= \pm\ 9.97$ cm

The equations explained 95 percent of total height variability. Dbh alone accounted for 85 percent of variation at Chiangmai. Similarly, needle weight accounted for 73 percent of total variation at Chumporn. For mineral composition, carbon and phosporus explained 9 percent of the total variation in tree height grown at Chiangmai and Mg explained 14 percent of variation at Chumporn. This is not a surprising result for young plantation. Working with the mixed conifer stands dominated by Douglas-fir in northern Idaho, Brown and Loewenstein (1978) also reported the similar findings that soil chemical properties explained 13 percent of the variation in tree height, while tree age alone accounted for 71 percent of total variation. In a manner similar to current investigation, Sirivalloph (1973) tried to associate height growth of Pinus kesiya grown in natural stands in northern Thailand with plant, soil, and topographic factors. Among 13 independent variables involved, only percent total nitrogen in A horizon could be representative of soil chemical properties included in multiple regression.

The general applicability of equations developed indicated that plant nutrients were not the major factors controlling tree height. Better growth performance gained from wet outplanting site may be due to the influences of greater amount of rainfall as well as of longer rainy period. From economic and biological point of view, therefore, it is unnecessary to apply fertilizer to both young pine plantations. However, fertilization might be reconsidered during its late rotation as trees become older and root systems are strongly competitive.

Conclusions

Conclusions derived from this study relied on the results of linear correlations between tree height and twenty-five soil-plant variables. In the field where chemical analysis is impossible, growth performances could be estimated from needle traits. Both foliage nutrients and nutrients in soil provided higher values of the correlation coefficients than those obtained from needle parameters. Soil analysis seemed to be slightly better height predictor than plant analysis did. However, nutritional problems explained only 9 percent of the total variation in tree height planted on dry site, and 14 percent on wet site. This suggested that fertilization was not necessary during its early rotation, especially if economic point of view was concerned.

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